Lightning Radiolocation

Richard J.S. Bates

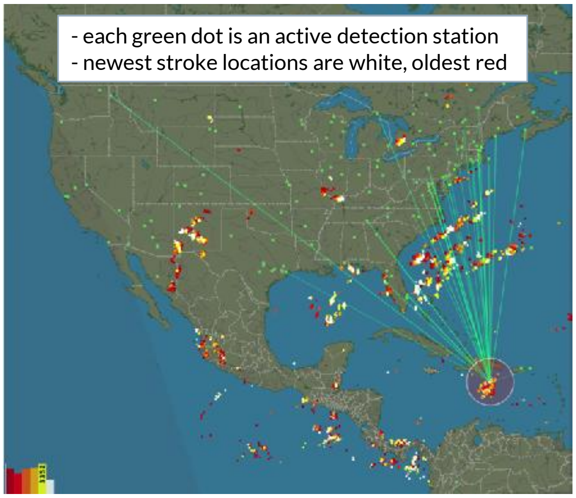
WD1O
richard.bates@stgeorge.me

September 2019

Outline

- Introduction
- Lightning – basics
- Radiolocation theory
- Detection station equipment
- Examples of data
- Single station distance accuracy
- Alternative lightning detection methods
- Obligatory xkcd.com reference
- Summary

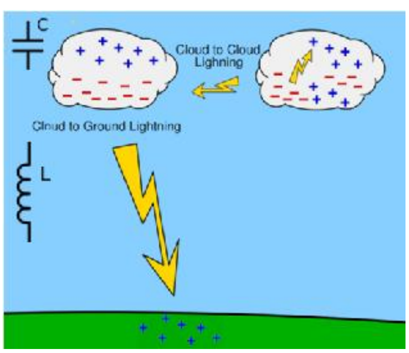
Introduction



- There are ~ 300 active volunteer lightning detection stations around world
- These stations report their exact location and arrival time of each detected "Cloud to Ground" stroke to a central server
- World-wide there are an average of 5 strokes each second
- Strokes can be detected thousands of miles away
- The lightning location is figured from these reports – typically ~50 reports per stroke

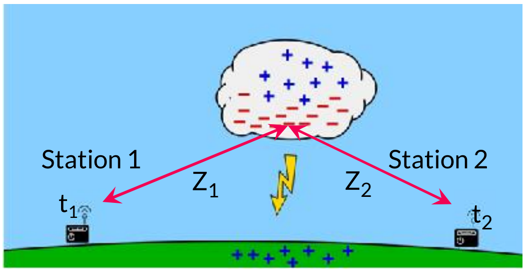
from http://en.blitzortung.org/live_lightning_maps.php?map=30

Lightning - basics



- In a typical "Cloud to Ground" stroke (R stroke), a charge Q ~ 1 C reaches the ground in τ~ 100 μs, so peak current ~10 kA
- "Cloud to Cloud" strokes (K strokes) typically occur $4\times$ more often than R strokes, but are typically $100\times$ weaker
- Sferics – the short pulse of electromagnetic radiation from lightning
- Simulated approximately by the electromagnetic radiation field of a vertical Hertzian dipole antenna
- R stroke maximum spectral energy around 1/τ = 10 kHz or λ ~30 km
- Beyond this maximum, spectral amplitude decreases as 1/f (theory) or faster (Sommerfield ground wave)
- The energy is reflected and attenuated on the ground as well as within the ionospheric D layer

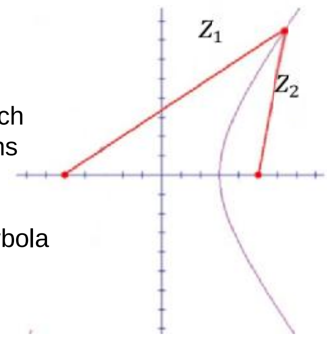
Radiolocation Theory - 1



Stroke travels distance Z_i to reach Station i at time t_i

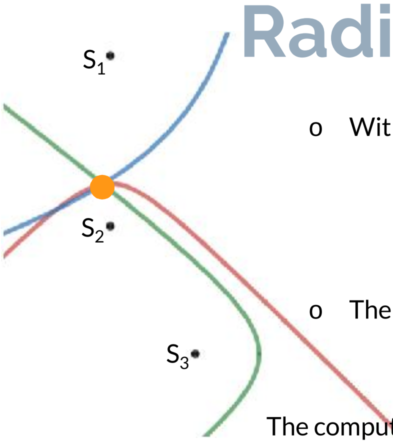
so that $(Z_1 - Z_2) = (t_1 - t_2) \cdot c$ .... *(1)*

where c = speed of light



- Equation 1 is a hyperbolic curve, since it defines a set of points such that the difference in the distance from the stroke to the two stations $(Z_1 - Z_2)$ is constant.
- Two stations locate the stroke somewhere on surface of this hyperbola

Radiolocation Theory - 2



- o With time stamps from 4 stations one defines 3 hyperbolic surfaces:

  - Stations S_1 and S_2 define the **red** surface
  - Stations S_3 and S_4 define the **green** surface
  - Stations S_1 and S_4 define the **blue** surface

- o The **orange** dot marks their intersection point – the lightning stroke

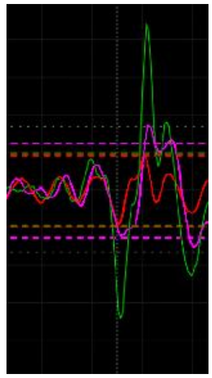
The computations at the server are carried out in two steps:

1. A starting point is computed using the method from the Koshak & Solakiewicz paper applied to the time stamps from the first 4 stations
2. A numerical method is used to minimize the sum of all squared distances to the hyperbolic curves.

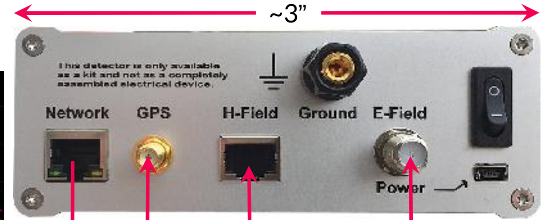
W.J. Koshak and R.J. Solakiewicz, "Time of Arrival Lightning Location Retrieval on Spherical and Oblate Spheroidal Earth Geometries", American Meteorological Society, February 2001.

Detection Station Equipment

Mostly surface-mount components



~3”



E-Field signal input

H-Field signal input from 2 horizontal orthogonal ferrite-rod-based antennas

GPS antenna input

E-field antenna & pre-amp

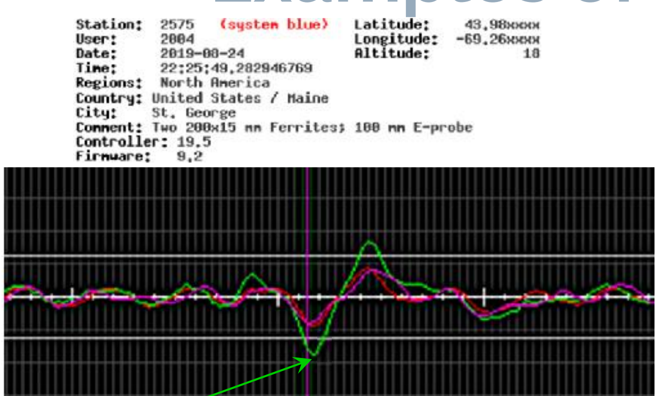
H-field antennas & pre-amps

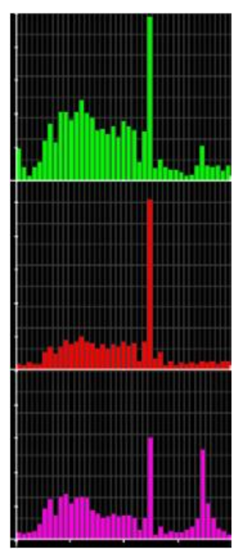
Example stroke detected in H-1, H-2 & E path

Time and Location stamp output to server via the Internet

richard.bates@stgeorge.me

Examples of Data - 1





H-1 signal

H-2 signal

E signal

H-1 signal

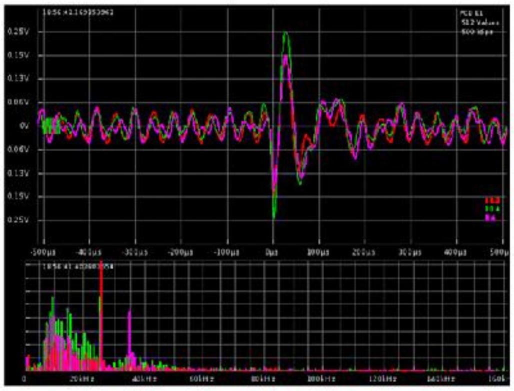
100μs

Time Response of a Stroke and the Corresponding Frequency Response

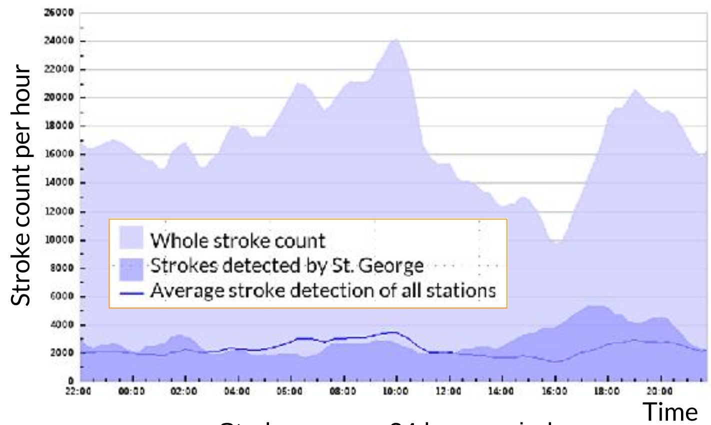
0 kHz 40 kHz

richard.bates@stgeorge.me

Examples of Data - 2

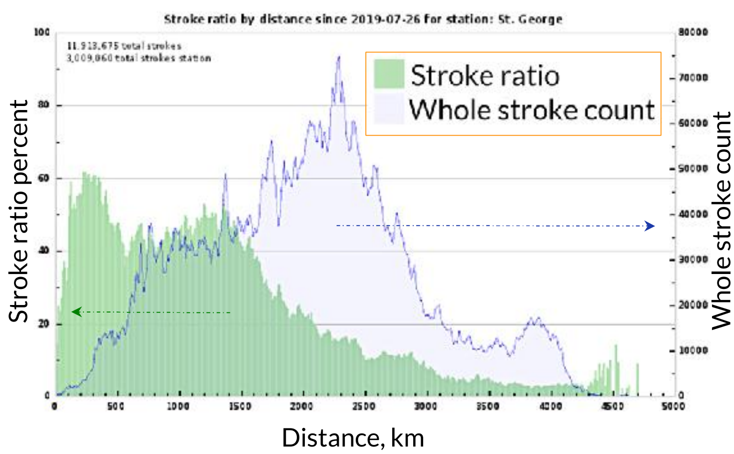


Another stroke example:
channels superimposed in both time and frequency



Strokes over a 24 hour period:
St. George compared to all stations

Examples of Data - 3



Station St. George (United States / Maine)

- **Record longtime data since:** 2019-07-26 23:07:28 UTC
- **Strokes detected:** 3,009,852
- **Station active:** 29.1 days
- **Station inactive:** 0.5 days (0.5 hours without GPS)
- **Max stroke count per hour:** 17,820
- **Minimum distance:** 7.5km
- **Maximum distance:** 13,584.1km
- **Signals detected:** 12,275,979
- **Stroke ratio:** 25.3%
- **Locating ratio:** 24.5%
- **Max signal count per hour:** 33,966

Stroke ratio = (detected strokes of the station) / (network stroke count)

Single Station Distance Accuracy - 1

Let the estimated time of the lightning stroke, using data from many stations = $\hat{t}_s$

and the estimated position of this stroke, again using the data from many stations, = $\hat{P}_s$

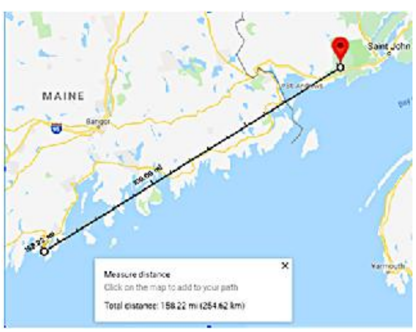
Now the estimated position of station i from the GPS data = $\hat{P}_i$

So the best estimated distance from the stroke to the station $\hat{Z}_i = \hat{P}_s - \hat{P}_i$

But if station i measures the arrival time to be t_i

then the single station estimate of the distance from the stroke to station i , $z_i = (t_i - \hat{t}_s) \times c$

Single Station Distance Accuracy - 2



From	To	# stations	Best Estimate $\hat{Z}_i$	Single Station Estimate z_i	Difference, %
St. John's, New Brunswick	St. George, Maine	57	254.6 km	255.5 km	0.35
West Palm Beach, Florida	St. George, Maine	124	2,110.2 km	2,119.7 km	0.45

Alternative Lightning Detection Methods

Portable Lightning Detector :
It appears to be based on AS3935 Franklin Lightning Sensor IC - its lightning algorithm is broken up into three sub blocks:

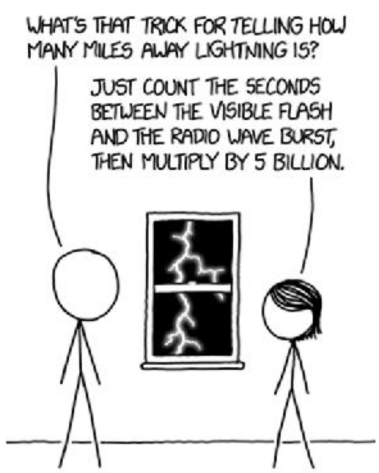
- 1. Signal validation: Verification that the incoming signal can be classified as lightning.
- 2. Energy calculation: Calculation of the energy of the single event.
- 3. Statistical distance estimation: According to the number of stored events (lightning), a distance estimate is calculated.

Geostationary Lightning Mapper (GLM) – part of GOES-16 satellite:

- A single-channel, near-infrared optical transient detector
- Measures total lightning (in-cloud, cloud-to-cloud and cloud-to-ground) activity continuously over the Americas and adjacent ocean regions
- Near-uniform spatial resolution of approximately 10 km
- Operated by NOAA National Weather Service

richard.bates@stgeorge.me 13

Obligatory xkcd.com Reference



from https://www.xkcd.com/2027/

- Refractive index of air is higher for VLF radio than at optical wavelengths, so radio propagates more slowly
- Speed of visible light (777 nm) in air at 15˚C is ~ 299,710 km/s
- Speed of VLF radio waves in same conditions is ~ 299,698 km/s
- Hence time difference of arrival between visible flash and radio wave burst ~ 0.2 ns/mile
- For comparison, difference of arrival between visible flash and thunder clap ~ 5 s/mile

richard.bates@stgeorge.me 14

Summary

- “Cloud to Ground” strokes typically have peak spectral energy ~10 kHz that propagates within the ionospheric D layer
- blitzortung.org – a world-wide amateur network of ~300 lightning detection stations
- Stations use magnetic and electric field antennas to detect “Cloud to Ground” strokes
- Signal processing in each station discriminates against noise and detects stroke peaks
- Server computes location of strokes by triangulation, using time and location data from detection stations
- Single station distance accuracy, even several thousand km from strokes, is within 0.5%

richard.bates@stgeorge.me